

# HOW TO INSTALL MAINTAINABLE BEARING TEMPERATURE SENSORS

by

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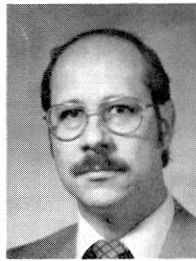
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## ABSTRACT

This paper covers techniques for retrofitting turbomachinery to accept "stab-in" type thermocouples for bearing temperature monitoring. The objectives of bearing temperature monitoring and shutdown systems are to (1) avoid machine wrecks caused by bearing failure and (2) to provide warning of impending bearing failure. The reliability of the sensor has a major impact on achieving these objectives. Improved sensor reliability is achieved by an installation that prevents damage to the sensor during machine assembly, and the ability to remove the sensor during operation for inspection or replacement. The emphasis is not in locating the measurement point, but how to get a sensor there.

## INTRODUCTION

Turbomachinery bearing temperature thermocouples can be installed so they are removable and replaceable while running. Over 150 bearing temperature thermocouples have been installed using the methods described here.

The objectives for a bearing temperature monitoring system are reliability, accuracy and maintainability. These objectives are met in the following ways:

- Reliability
- Using sheath type thermocouples.
  - Installing thermocouples in the machine after mechanical completion which avoids damage.
  - Redundancy: using two thermocouples in each bearing "voting" for shutdown.
  - Replaceability: the thermocouples can be changed out during machine operation.

- Accuracy
- The thermocouple reads the temperature close to the load point in the bearing.
  - The springiness of the sheath provides spring loading in most installations.
- Maintainability
- The thermocouples are easily removed prior to a machine overhaul and quickly reinstalled afterwards. They are easily and quickly checked for operation and location, and easily changed out if there is any question in their condition.

The procedure used includes these steps: locating the load points, determining the routing, laying out the bearing for drilling, the actual drilling, reassembly of the bearing, and, finally, installation of the thermocouple.

## LOCATING THE LOAD POINTS

The highest temperature in a bearing is at its load point. This point may be calculated from the bearing dynamics and loads, such as gravity, gear loads, etc. There are many excellent references [1, 2, 3, 4] for such calculations; however, some "rules of thumb" are:

1. For sleeve bearings: 15°-30° with rotation from the bottom.
2. For tilting pad journal bearings: the bottom pad 25% from the trailing edge.
3. Journal bearings on gears: the gear load is usually much greater than gravity and the other loads.
4. Shoe type thrust bearing: 25% from the trailing edge and 25% from the outside circumference, of any pad.
5. Within 15 degrees of the load point usually gives acceptable readings.

## DETERMINING THE ROUTING

Once the load point has been located, one end of the thermocouple has been located. Now a suitable exit point must be found and a path between these two points must be selected. The points to consider are:

1. Allow room for fittings where required. Particularly note obstructions on the outside of the machine where the exit point is to be. It wouldn't do to come out right where an oil line flange is in the way of the fitting.
2. The straighter the path, the easier.
3. The more perpendicular to the shaft the path is, the easier.
4. Solid metal is better. Voids, such as oil sumps, can be handled, but solid metal is usually easier, unless a curved path is required.

5. Curves can be three-dimensional. "Cork-screw" type routings have been performed.
6. Large voids (more than four times the thermocouple diameter) must be crossed with tubing. The tubing must be held at each end, and often sealed.

Figures 1 through 9 give tips for solving most routing problems.

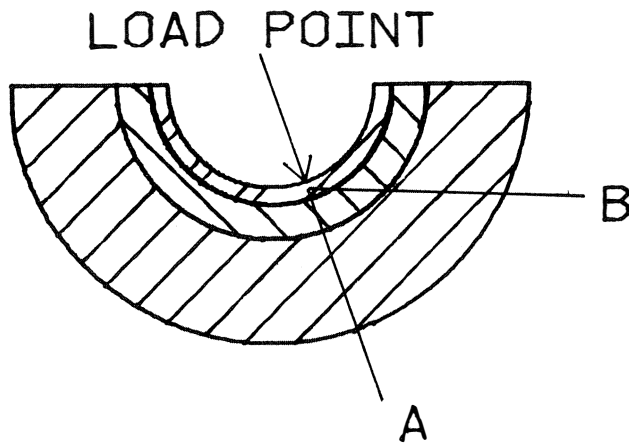


Figure 1a. Path A is the Easiest to Drill, but Path B May Be the Easiest to Fit Up on the Outside and It is Not That Much More Difficult.

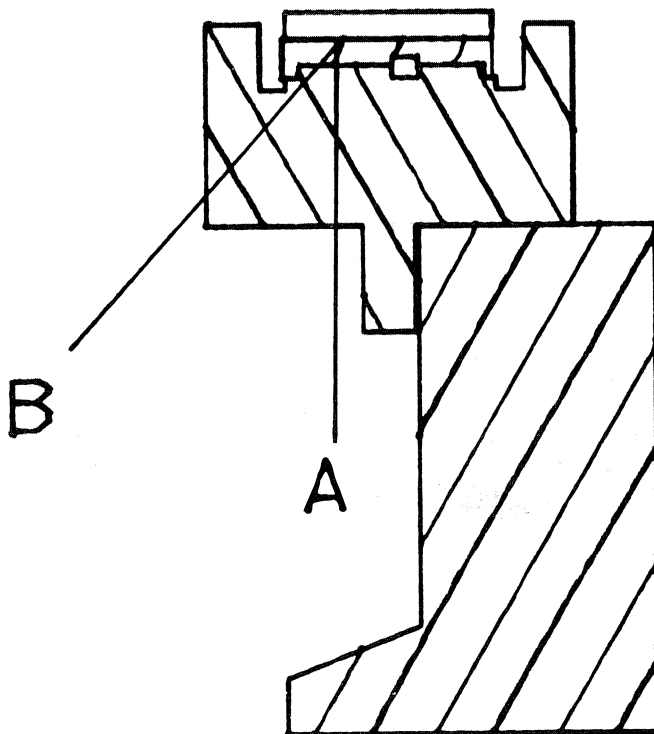


Figure 1b. Path A is Easier to Drill Because Path B Involves Complex Three-Dimensional Angles.

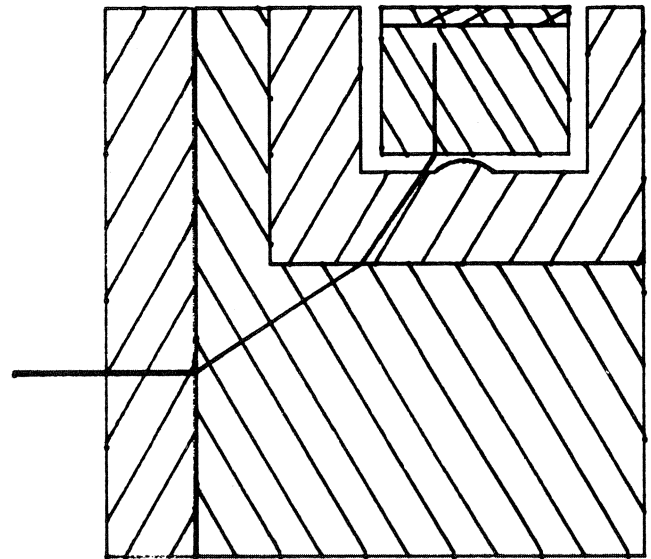


Figure 2. If a Straight Path is Not Practical, Each Metal-to-Metal Interface can Give an Angle Change.

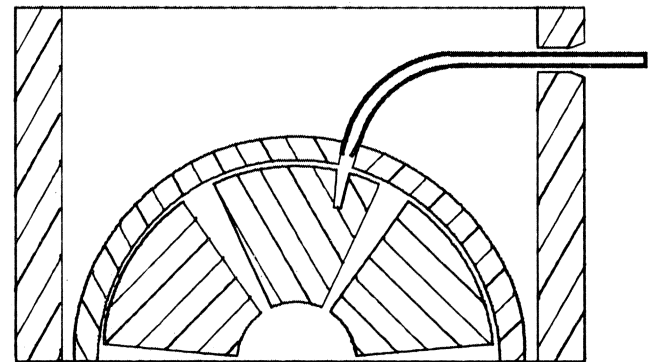


Figure 3. Another Way to Make a Curve is With Tubing Crossing a Void.

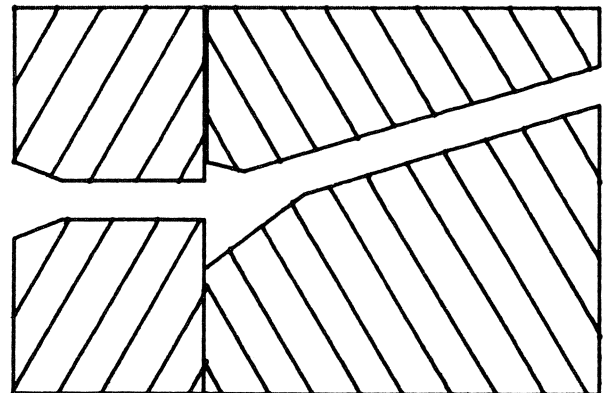


Figure 4. Chamfer the Incoming Side of Each Metal-to-Metal Interface to Avoid a Shelf Where the Thermocouple Might Hang Up.

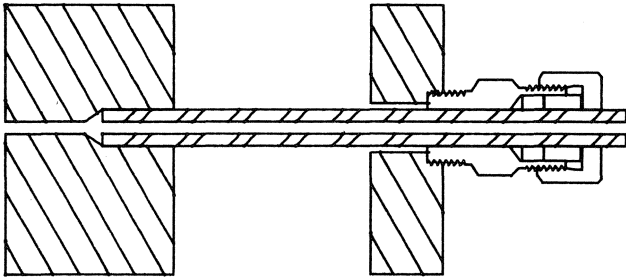


Figure 5. Voids Must be Crossed with Tubing, and the Ends Held. If tight sealing is not required, a hole, the diameter of the tubing, drilled for an inch or so will hold one end (polish one end with emery cloth) when it has been tapped in. Welding or brazing is required if a pressure seal is required, and a fitting won't fit.

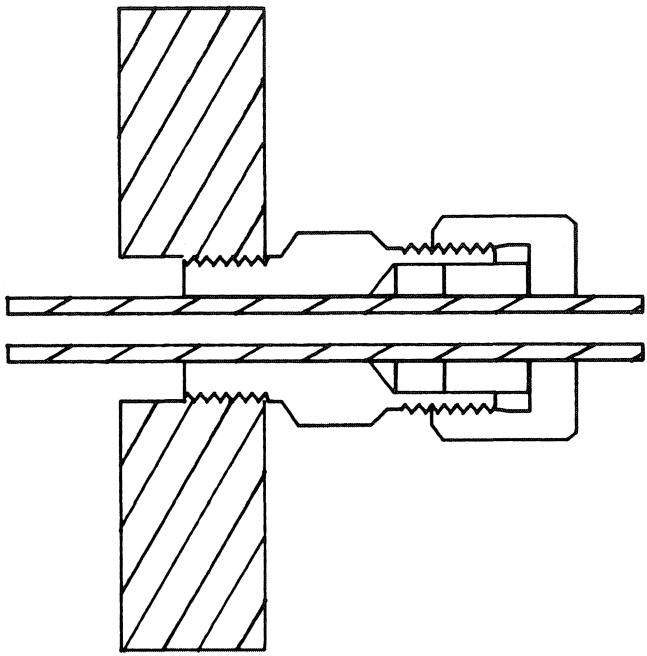


Figure 8. A Thicker Wall can be Drilled and Tapped for a Gland Fitting on the Inside or Outside.

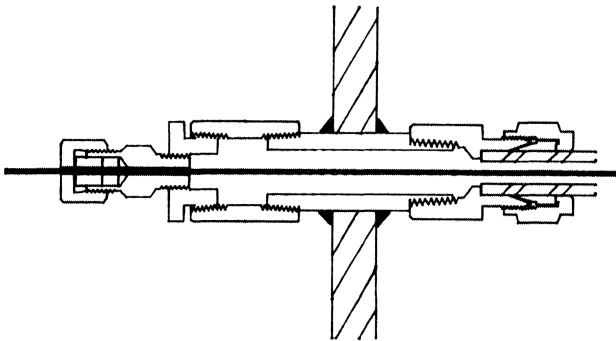


Figure 6. A Nipple Welded in a Hole in a Thin Wall.

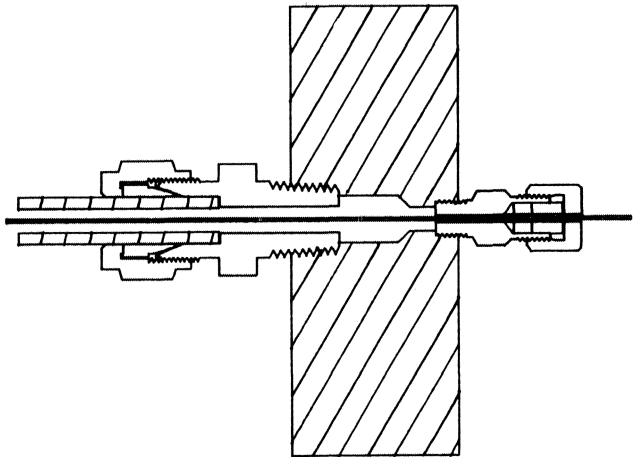


Figure 9. A Very Thick Wall can be Drilled and Tapped for a Tubing Fitting on the Inside and a Gland Fitting on the Outside.

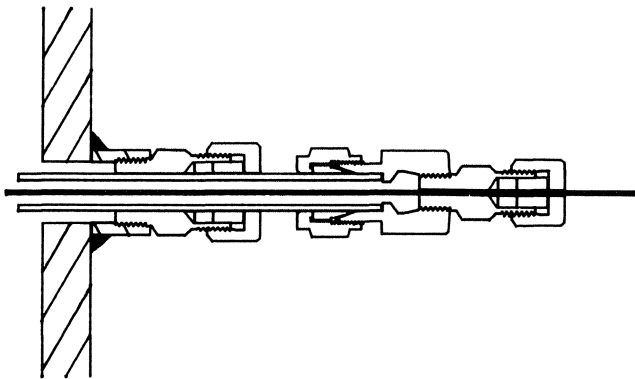


Figure 7. A One-Half Pipe Coupling Welded on a Thin Wall With a Gland Fitting (or Drilled Out Tubing Fitting).

## LAYOUT AND DRILLING

Once the routing has been determined, the actual drilling angles must be laid out on the pieces. Start with the most difficult or most critical hole. The most difficult is the longest or where the hole must be precise in order to miss voids, etc. After the first hole is drilled, use it as a template to mark the pieces on either side. Continue working this way using each piece to mark the next. The objective in laying out a piece is to put a mark (usually a center punch mark) where the drilling is to be started and to measure and mark the two angles which are required to specify the direction of drilling.

The following procedure, along with Figures 10 through 22, is a starting point for laying out and drilling. This step is difficult to describe, but is much clearer when actually performed.

1. Spray or paint layout dye on the piece.
2. Using the adjacent piece as a template, mark the starting location and project that point to the other side of the piece assuming a straight line through the centerline of the shaft.
3. Scribe on the split line, and a milled surface perpendicular to the center line, the projections of the line from Step 2. See Figures 10 and 11 for examples.

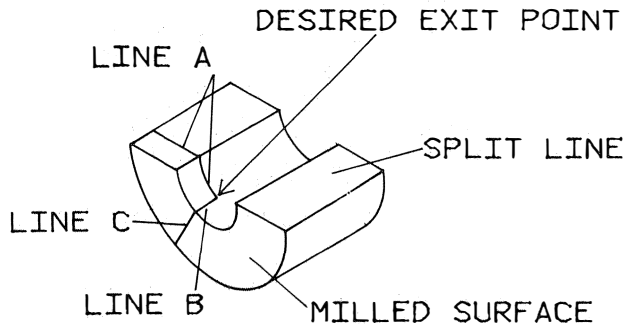


Figure 10. Line A is Parallel to the Milled Surface, Line B is Perpendicular to the Milled Surface, Line C is Found Using a Circle Center Finder. The exit point is marked from the adjacent piece.

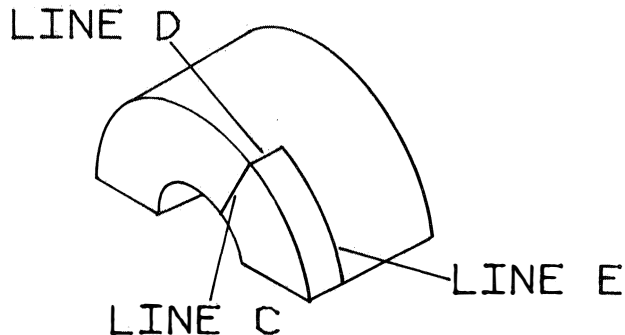


Figure 11. Line D is Perpendicular to the Milled Surface and Line E is a Continuation of Line A.

4. If the projection of the marked location is not a suitable point, then mark the best location. Best is a combination of most suitable and what is practical, considering drilling, thermocouple bend radius, angle between adjacent pieces, etc.
5. Scribe on the split line and the milled surface the projection of the line from the selected location from Step 4 to the marked starting point from Step 2 (Figures 12 and 13).
6. Measure the angles on the split line and the milled surface (Figures 14 and 15). The total angles should not be more than  $15^\circ$  from the angles in the adjacent pieces and less than  $7^\circ$  is preferred.
7. Center punch the piece.

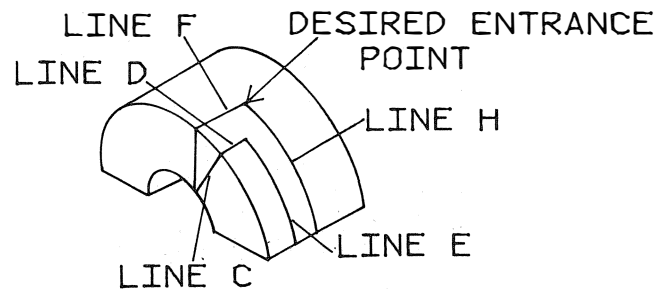


Figure 12. Line F is Perpendicular to the Milled Surface and Line G Connects the Ends of Line F and Line C. Note that Line G will not go through the center of the bearing. Line H is parallel to the milled surface.

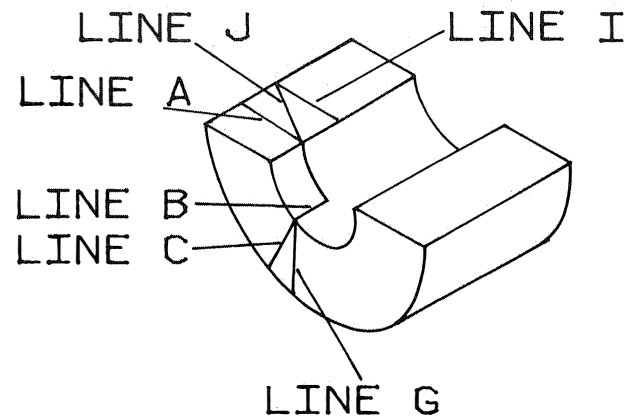


Figure 13. Line I is a Continuation of Line H, Line J Connects the End of Line I and the Point on Line A at the Inside Radius.

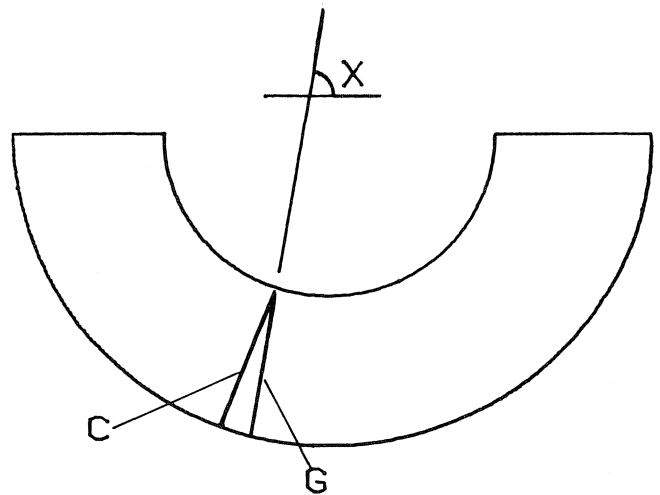


Figure 14. Measure the Angle X Between the Split Line and the Line G.

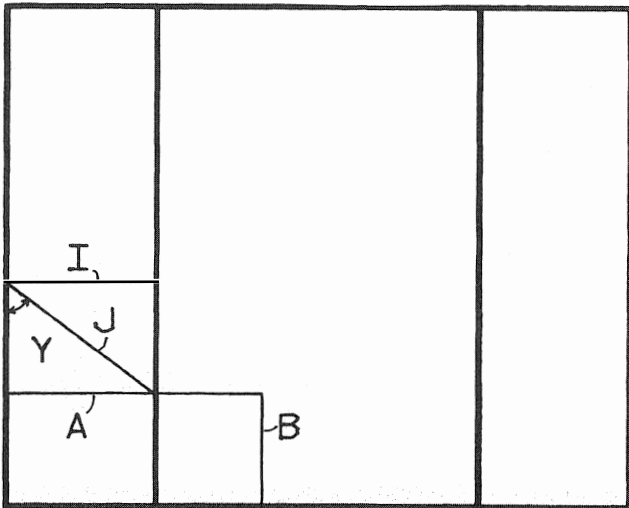


Figure 15. Measure the Angle Y.

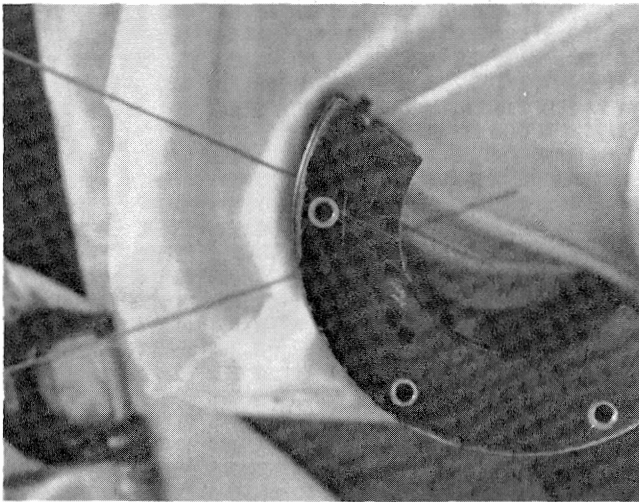


Figure 16. Putting Two Thermocouples Into the Same Pad Often Requires Two Different Angles.



Figure 17. After the Piece is Drilled, use it as a Template to Mark the Next Piece.

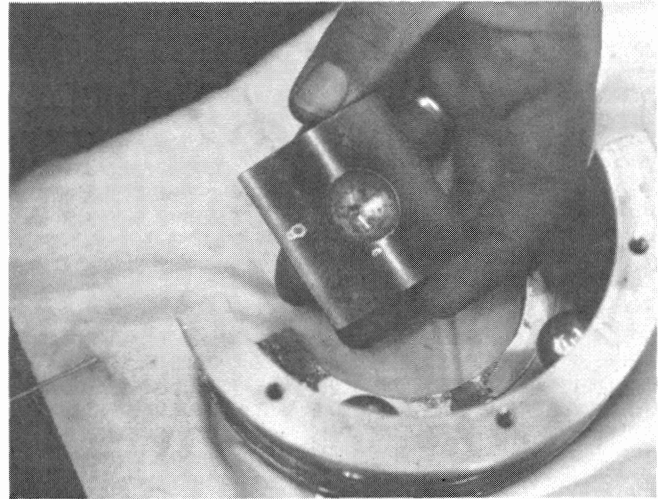


Figure 18. Check the Next Piece for Good Alignment.

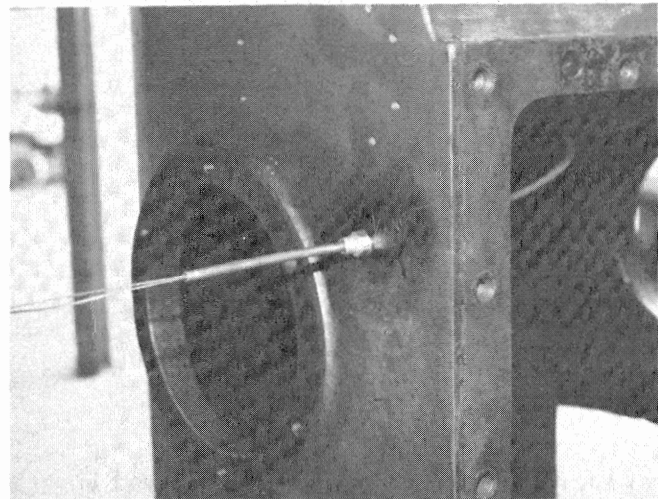


Figure 19. Tubing Lead Through a Bulkhead can be Sealed with a Drilled Out Tubing Fitting. Fittings to seal the thermocouple would be added on to the end of the tube.

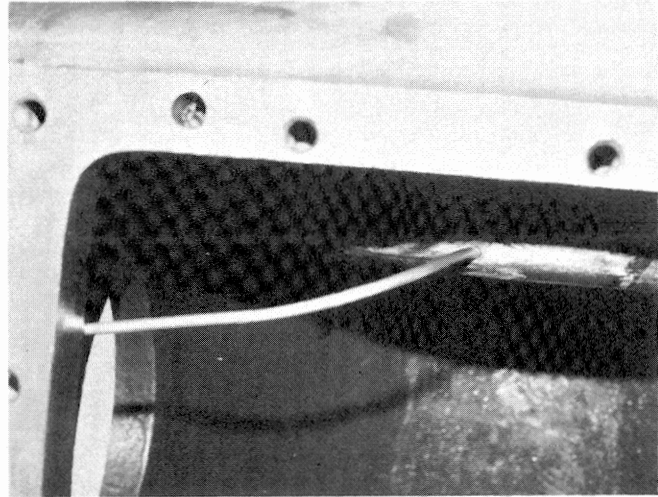


Figure 20. If Pressure Sealing is Not Required the Tubing can be Pushed Through the Same Size Hole.

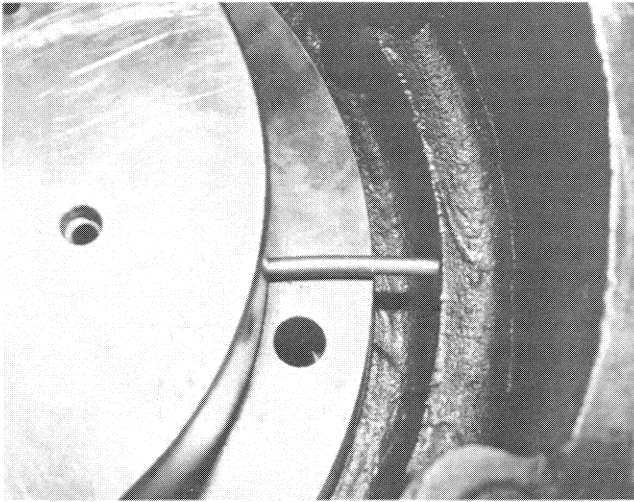


Figure 21. Some Sealing can be Achieved by Tapping the Tubing Into a Hole Which is not Drilled All the Way Through.

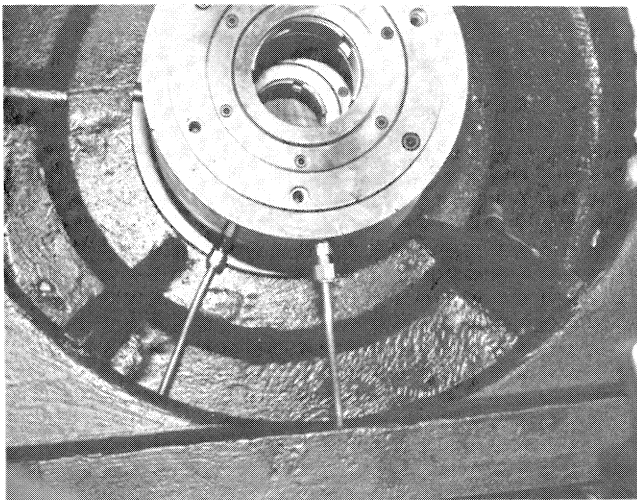


Figure 22. If There is Room, Tubing Fittings Should be Used for Ease of Installation.

This process is made more difficult if there isn't a split line surface or a milled surface to use for layout and measuring the angles. When this occurs and the angles and locations are not critical, the drilling can be estimated. For example, on a hole going to the outside of a housing where the housing cannot be moved and a foot or so of tubing will connect to the next piece, the tubing can take up any error in the drilling. If the angles and locations are critical, then construct a split line or plane with scales (Figure 23). First, put the piece on a flat surface, orienting the center line parallel or perpendicular to the surface. Clamp the piece so it cannot move (a heavy piece need not be clamped). With the table or flat surface as a reference, and using scale holders, square rule clamps and scales, build a frame on the outside and inside of the piece in the plane that the hole will be drilled. Make the appropriate measurements and calculate the angles using trigonometry. A further refinement is to take the measurements and make a 1:1 scaled drawing. If one end is more critical than the other, start the

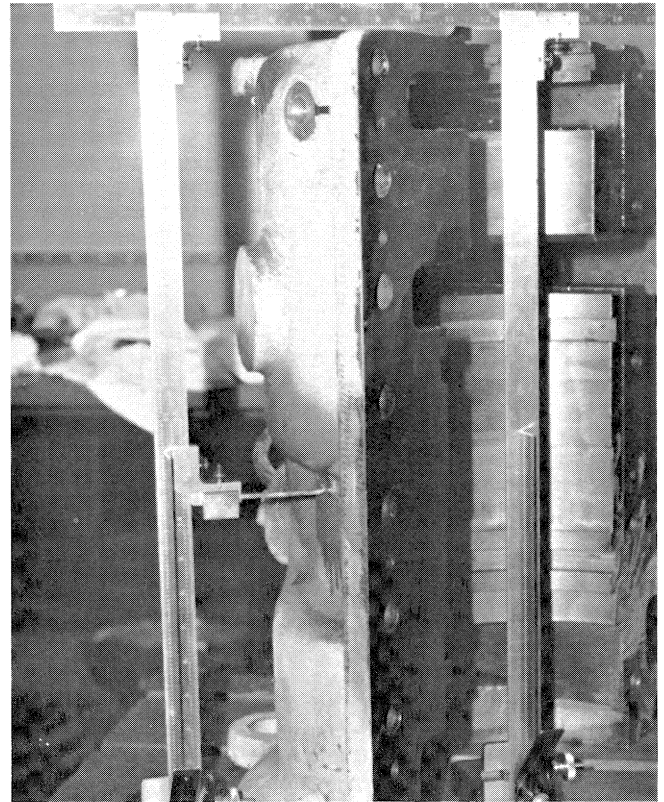


Figure 23. A Reference Plane can be Constructed of Rules and Rule Holders.

hole on that end. A good rule to follow in a case like this is to drill the most difficult or error prone hole first and then fit the other pieces to it.

## DRILLING

Setting the piece up in the drill press or milling machine is sometimes more difficult than laying out the piece. Even given a center punch mark to start from and the angles, some thought must be given to mounting the piece for drilling, especially for compound angles. A milling machine is often used for compound angles because the piece to be drilled can be set up and rolled in the vice for one angle and then the head on the milling machine can be rolled for the other. Also, the mill can spot face a flat spot to prevent the drill from walking. In any event, when drilling a compound angle, care must be taken because after one angle has been set, rolling the piece for the second angle may change the first angle if the second angle is not made in a plane parallel or perpendicular to the center line. Figures 24, 25, and 26 show this process.

*A word of caution:* After setting up to drill, the set-up on a complicated angle should be **TRIPLE-CHECKED!** Seventy percent of all errors are made in this step. At least two people, and preferably three, should verify the angles and set-up. Re-measure all angles using protractors, squares and levels. Try to visualize where the hole will come out. Don't assume anything, especially the order in which the angles were set.

When drilling the pad from a tilt-pad type bearing, or a regular bearing, the end of the thermocouple hole should be approximately  $\frac{1}{16}$  in. from the back of the babbitt. This depth is measured and the stop set on the drill press or milling



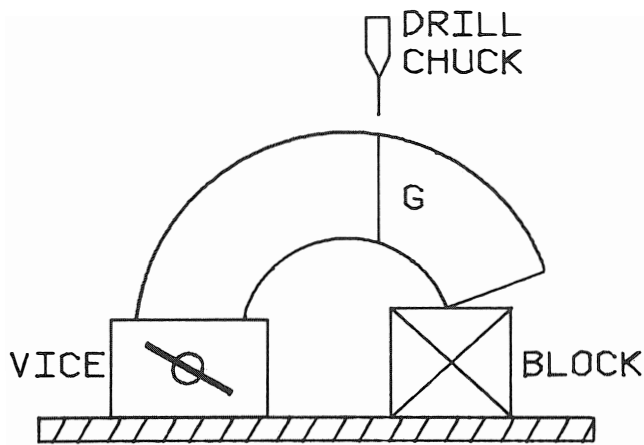


Figure 24. Clamp the Piece so that Line G is Vertical. Check by moving the table so a drill placed in the chuck will line up on the line.

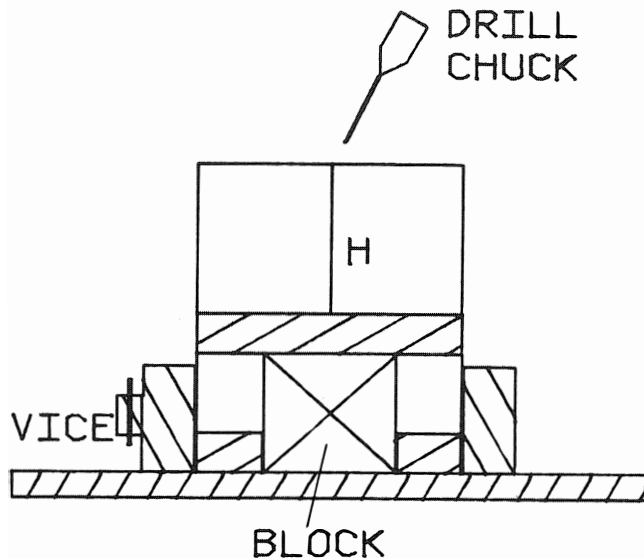


Figure 25. Roll the Head of the Milling Machine to Angle Y.

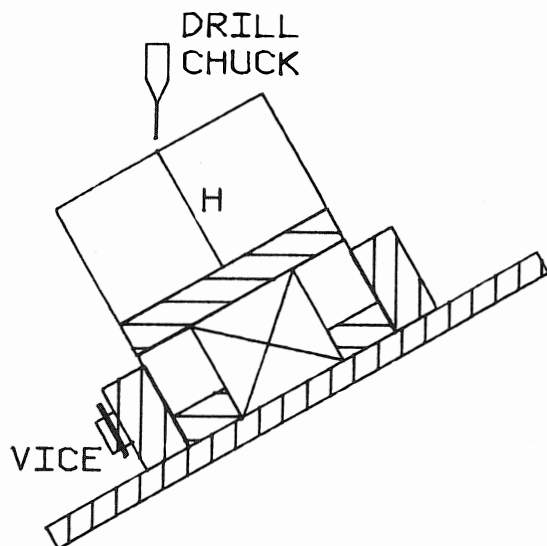


Figure 26. The Table can be Rolled Instead of the Head.

machine. A good check is to move the drill to the end of the pad and the stop compared to the bearing, as shown in Figure 27.

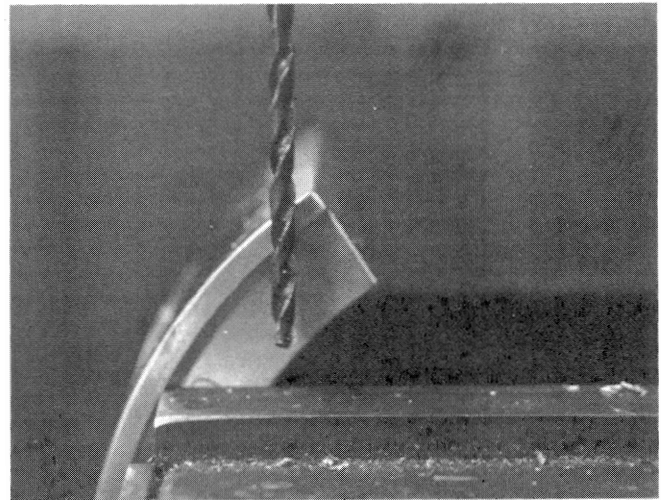


Figure 27. Set the Stop on the Drill Press so that the End of the Hold is  $\frac{1}{16}$  in. From the Back of the Babbitt.

The recommended hole size is  $\frac{1}{8}$  in. for a  $\frac{1}{16}$  in. thermocouple and  $\frac{3}{16}$  in. for a  $\frac{1}{8}$  in. thermocouple, although  $\frac{1}{16}$  in. is often used for  $\frac{1}{16}$  in. thermocouples.

After drilling the hole, add the chamfer. If the thermocouple is coming in at a different angle than the hole, it is sometimes better to change the angle of the chamfer to approximately the incoming angle. The chamfer should have no steps or sharp edges. These can be taken off with a scraper or round "rat-tail" file. The resulting hole is shown in Figure 28.

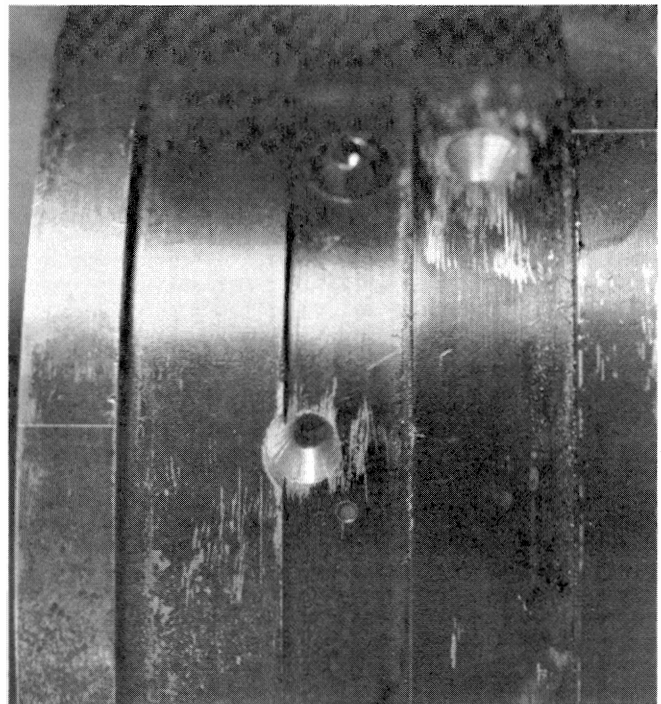


Figure 28. After Drilling, Chamfer the Hole.

## ERROR CORRECTION

If, in spite of all the precautions, the hole didn't go where expected, all is not lost, except on a pad drilled through the babbitt. The two basic problems that can occur are 1) the hole came out in the wrong place, or 2) the hole came out okay, but went through a void it wasn't supposed to (such as an oil supply groove).

In the first case, the hole must be plugged and then redrilled. The plugging can be done with a steel or brass plug made to fit and tapped in, or the hole can be threaded and a threaded plug or bolt installed. The head of the bolt can then be cut down on a lathe or milling machine.

The second problem can be solved with tubing. First, re-drill the hole for the next size tubing, past the void. Then tap in the tubing. Finally, drill the tubing down inside the piece so that it forms a chamfer.

## REASSEMBLY OF BEARING

After each piece is drilled, it should be fitted with its mating pieces, and a stainless steel welding rod put through the thermocouple hole. This will ensure that the thermocouple will not bind up on lips or angles. Clear up any places the rod hangs up with a file or scrapper, or by re-chamfering or re-drilling. Before the shaft is installed, the welding rod should be put through the thermocouple hole all the way from the outside into the bearing or pad. By holding the pad with one hand, ensure that the welding rod has bottomed out. Measure this insertion depth and mark it on the outside of the hole. Be sure to give the depth measured to the outside of the case or some non-movable piece, as the fittings will vary in length as they are made up.

When the installation has several twists or metal interfaces, sometimes a small (5°-10°) kink on the last ½ in. of the thermocouple will help insertion. Also helpful is twisting the thermocouple or making a "crank" and turning it.

## OTHER CONSIDERATIONS

One concern often expressed about installing sheath thermocouples in tilting pad bearings is about the effect on the bearing. "Won't the thermocouple pre-load, or cock the pad?" This is not a problem except with very lightly loaded, small pads and large (½ in. or larger) thermocouples that are clamped close to the pad in a direct line. Most installations have enough bends that the thermocouple is side loaded, which is only ounces of force on a ⅛ in. thermocouple. This is, in fact, the preferred way to install a thermocouple so that the spring in the thermocouple serves to hold it against the pad.

All of the techniques described so far were developed for retrofitting machines. The same techniques can be used in the design stage of a new machine with a couple of additional options. Instead of crossing a void with tubing, a web can be cast or a support placed in the best place. Instead of milling a flat or welding a coupling for a fitting, a raised boss can be cast into the piece.

## DIAGNOSTICS AND ALARM SETTING

Acceptable bearing temperatures depend on the surface velocity of the shaft and the load on the bearing. The generally accepted maximum temperature at the surface ranges from 150°C to 160°C (over 170°C with damage, but without total failure, has been reported [2]). The temperature at a thermocouple installed ¼ in. from the surface may be 40°C or more cooler than the surface. For most machines with moderately loaded bearings, 120°C to 130°C is a good value for a maximum

temperature at the thermocouple. Alarm and shutdown set points of 100°C and 120°C are acceptable for most bearings. The load and inlet oil temperature affect the bearing temperature and many bearings will run under 75°C for which a lower alarm point is practical.

Bearing failures detected by bearing temperature monitoring have several patterns. One is a steady increase in temperature at constant load, speed and oil inlet temperature. The time between alarm and shutdown levels can vary between a few seconds to several weeks. A second pattern seen is seemingly random changes with several increases into alarm and/or shutdown levels and then decreasing down to even below normal running temperatures. Some failures of this type make only one excursion above the shutdown point to between 150-200°C and then return to below normal running temperature. The time involved is usually several seconds to several minutes. After melting the babbitt from a bearing, the rotor may start riding on a seal and the bearing temperature could come down to near the inlet oil temperature. A bearing, when severely damaged, may begin to turn in the housing, shearing the thermocouple, which can result in a short or open thermocouple indication.

Unfortunately, several thermocouple problems can mimic these patterns. A loose and sliding connection can produce random temperature changes usually above the actual temperature. Most of these failures occur over several hours or days, which is considerably longer than the usual bearing failure. An open thermocouple will trend up quickly to several thousand degrees. A short will read ambient temperature which is below the inlet oil temperature.

Briefly, then, a bearing failure is indicated by:

1. A steadily increasing temperature over several minutes or days to a range of 110-200°C.
2. A series of random "spikes" of a few seconds or several minutes, to temperatures of 100-200°C.

Thermocouple failures are indicated by:

1. A reading above 200°C (not always, see example below) or below the inlet oil temperature.
2. A series of random "spikes" over several hours or days.

Given the time after a bearing temperature alarm, it is a good practice to check the instrumentation (or better yet, have a redundant reading); however, if there isn't enough time, it is wise to believe the thermocouple. An example will illustrate the point.

During the start-up of a compressor, the bearing temperature trended up with speed to a normal operating temperature. Suddenly the temperature started increasing and in 15 or so seconds was over 1000°C. The reading acted exactly like an open thermocouple and was assumed to be such. What had actually happened was that the bearing had lost oil, the babbitt had melted out (at around 180-200°C) and the bearing and journal had gone to steel. There was sufficient friction to melt the shaft at several thousand degrees. Needless to say, within seconds (20 seconds or so after the first alarm) the machine vibration became violent and smoke poured out of the bearing housing. The next time the machine was started, the bearing temperature shutdown was not bypassed.

## CONCLUSION

Using the techniques described, reliable and easily maintained bearing temperature sensors can be installed. All it takes is good planning, care, and experience, all of which are widely available in industry. Not all of the attempts will be successful, either from bad drilling or layout, or the ther-



mocouple just wouldn't go in as easily as planned. However, the number of successful installations and saves due to bearing temperature monitoring justify continuation of this method of mounting thermocouples.

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